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RESEARCH REPORT

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REPORT NO. FIVE

TITLE: THE ROLE OF VESTIBULAR NYSTAGMUS IN THE VISUAL PERCEPTION OF A MOVING TARGET IN THE DARK

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SUMMARY:

Six well-trained subjects reported their visual perceptions both during and following rotation while observing a moving target in the dark and in a lighted room. The subjects were rotated at speeds varying from 2 to 15 rpm both to the right and left, while the target described a circular path 2 meters distant and 15° above the level of the subjects' eyes. The subjects were asked to give a qualitative description of their own sensations of rotation and of the apparent movement of the model plane during and following rotation.

When a subject was accelerated to 15 rpm in the dark, there was a rapid displacement of the target in the opposite direction, although, at the same time, as a result of nystagmus the target appeared motionless. This paradox made it necessary for the subject to distinguish between rate of motion and amount of displacement. As the target went by on successive rotations, it appeared to pass more rapidly until, after approximately 30 seconds, the subject felt himself to be stationary while the target rotated rapidly around him. Similar results occurred at slower speeds of rotation.

The post-rotation phenomena were stronger, since the deceleration was more rapid. Following cessation of rotation to the right at 15 rpm the target appeared to move very rapidly to the left, and in some cases even appeared momentarily to be displaced to the left. Then the subject observed rapid motion to the left, while he was required to turn his eyes to the right to follow the target. Following cessation of rotation to the left, the target appeared to rush rapidly to the right while it was displaced to the right very slowly. Similar but less pronounced results were observed using slower rotation speeds.

These phenomena which did not occur in a lighted room can be considered as a summation of the effects of real motion of the target, vestibular nystagmus, and the subjects' sensations of their own motion. The causal factors are similar to those found in certain other types of apparent motion. These effects have important implications in the explanation of "vertigo" in pilots.

INTRODUCTION:

The present report is concerned with the illusory effects produced by rotation during the visual perception of a moving object and represents an extension of earlier studies [1,2] in which the fixation object was stationary. These earlier studies showed that if a subject is rapidly rotated in the dark while regarding

[1] A. Graybiel and B. Clark, The autokinetic illusion and its significance in night flying, J. Aviation Med. 16: 111, 1945.

[2] A. Graybiel and D. Hupp, J. Aviation Med. (In press) The oculogyral illusion: a form of apparent motion which may be observed following stimulation of the semicircular canals.

a light which is stationary with respect to himself, two series of illusory movements are observed, the first as a result of acceleration and the second as a result of deceleration. With the onset of rotation the target light appears to move in the direction of the turn, but, if the speed of rotation is uniform, the velocity of apparent motion gradually diminishes and the target comes to rest. This may be followed by apparent motion in the opposite direction which lasts for a short period of time and is of small practical consequence. During the remainder of the turn the target usually appears motionless. Following abrupt cessation of rotation the target appears to move rapidly in a direction opposite to that of the previous rotation. This effect may last for half a minute with the velocity gradually diminishing and may be followed by two additional pendulous movements of a minor character. The term oculo-gyral illusion has been given to the apparent motion produced in this manner by stimulation of the semicircular canals, and it is important for our purpose to re-emphasize that only the first movement following acceleration and deceleration are strong illusions.

This phenomenon can be explained, in large part at least, by the nystagmus which is produced reflexly following stimulation of the sensory end-organs of the semicircular canals. If, for example the horizontal canals are stimulated by rotary acceleration of the subject to the left, the nystagmoid movements of the eyes produce a series of alternate slow movements to the right and fast movements to the left. The eye movements themselves are not perceived. Visual perception during the fast phase is disregarded while that during the slow phase is relatively clear. Therefore, the eye movements produce a tracking of the image across the retina to the right which is perceived as a movement of the object rather than of the eyes. These movements are summated to produce a perception of motion to the left for the duration of the nystagmus. For a comprehensive survey of the pertinent literature the reader is referred to the excellent reviews by Speigel and Sommer[3], Dusser de Barrenne[4], McNally and Stuart[5], and Boring[6].

In the experiments now to be described the perception of the real movement of the target was purposely complicated by vestibular nystagmus which produced such bizarre effects as causing the target to appear to move rapidly to the left yet be displaced to

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[3]F. A. Spiegel and I. Sommer. Med. Physics, Chicago, The Year Book Publishers, Inc. 1944.

[4]J. G. Dusser de Barrenne. "The Labyrinthine and Postural Mechanisms" in C. Murchison. Handbook of General Experimental Psychology, Worcester, Mass., Clark U. Press, 1934.

[5]W. J. McNally and E. A. Stuart, Physiology of the labyrinthe reviewed in relation to seasickness and other forms of motion sickness. War Medicine, 1942, 2, 683.

[6]E. G. Boring, Sensation and Perception in the History of Experimental Psychology. New York, D. Appleton-Century Co., 1942.

the right. This necessitated a sharp distinction between rate of motion of the target on the one hand and amount of displacement on the other. In this paper motion refers to that perception which defines a body as not being at rest, while displacement refers to a change in location of an object relative to the observer.

METHOD:

All of the observations were made in a twelve-sided, air-conditioned, light-proof room. The walls were made of 12 four-foot panels. The lower six feet of the panel was black while the upper four-foot section was grey. The model plane was always viewed against the grey background.

The apparatus used consisted of: (1) a Link Trainer which was modified so that it could not pitch or bank but could be rotated at various speeds up to 25 rpm by the experimenter only, and (2) a model plane which served as a fixation object. The subject communicated with the experimenter in the next room by means of the Link Trainer's intercommunication system. The Link Trainer was mounted in the center of the room and could be rotated continuously either to the right or left. The model plane was fixed at the end of an arm which rotated about the subject's head to the right only, at 0.95 rpm; the plane thus described a path of circular flight 2 meters distant and 15° above the level of the subject's eyes. This resulted in the plane's being visible throughout a 120° arc in front of the subject; thus the plane was visible to the subject for a period approximately one-third of the total time of each of his rotations. The model plane had a wing span of 50 cm and a length of 38 cm. Three lights (2.6 mm in diameter) were visible on the plane: port and starboard wing lights and a tail light.

The subject was seated in the Link Trainer with his head inclined approximately 25° forward to obtain the maximum stimulation of the horizontal canals during rotation. A bite board was used to minimize head movements. Six subjects who had made many observations of similar effects during and after rotation acted as observers.

Each subject reported the velocity and direction of motion and the amount of displacement of the plane relative to himself both during and after rotation until all motion ceased. These reports comprised a qualitative description of the subject's sensations of his own rotation and of the motion of the model plane, its direction and speed. No attempt was made to differentiate between real and apparent movement. Under these conditions both were involved, and in any case, previous experiments contain ample evidence that the subject cannot always differentiate between them. Since the target light was visible only about one-third of the time, these data do not lend themselves to precise quantification.

Prior to each trial the model plane was set in motion. The rotation of the observer was started and stopped in such a relation to the model plane that it would, in spite of its own rotation to the right, be in view for a maximum period of time following the onset and offset of rotation. The signals for starting and stopping were given by the subject and were determined by the relative motion of the plane and the subject. The subject was always stopped with the plane at his extreme left, which gave maximum duration of visibility of the plane while it passed through his field of vision. Trials were run for each subject at different speeds from 2 to 15 rpm both to the right and to the left. In each trial the subject was rotated well beyond the time when the acceleration effects could interfere with the post-rotational phenomena.

RESULTS:

In the dark, with the subject rotating more rapidly than the target, the apparent motion and the displacement of the target plane were affected primarily by three variables: (1) the actual relative movement between the subject and the target; (2) the subject's perception of his own motion, and (3) ocular nystagmus which resulted in the oculo-gyral illusion. When the room lights were turned on and the subjects rotated at the same speeds, the subject's fisual perception of his own motion was sufficiently prepotent so that the real movement of the target plane was correctly perceived, and the illusions of relative movement were largely abolished.

1. Acceleration effects:

When the subject, at rest in the dark and watching the target move slowly to the right, was abruptly accelerated to the right to 15 rpm in 4 seconds, the target appeared immediately to lose all motion, but, paradoxically, was rapidly displaced to the left and out of view. On its next appearance, the target showed slight motion to the left and rapid displacement to the left. With each successive rotation there was an increase of the velocity of apparent motion of the plane to the left. The subject's sensations of rotation decreased, until he felt himself to be stationary while the model plane rotated rapidly around him. This occurred between the fourth and sixth appearance of the plane or 15 to 30 seconds after onset of rotation. By this time the rate of motion and the amount of displacement of the target appeared harmonious.

Similar though less marked effects were observed at slower rotation speeds. When the subject was accelerated within a half second from no motion to 3 rpm to the right, there was again a noticeable discrepancy between the amount of displacement to the left, which was considerable, and the slow apparent motion to the left. The subjective sensations of turning right again waned and the apparent motion of the plane to the left increased until the subject felt himself stationary with the plane revolving around him. This became stabilized by the time of the third appearance of the target.

When the subject was accelerated to the left to 15 rpm within 4 seconds, the target immediately appeared motionless, although at the same time it was gradually displaced to the right until it disappeared. On successive appearances the target plane appeared to be moving and undergoing displacement to the right, gathering velocity as the subject's sensations of his own rotation waned. The discrepancy between rate of apparent motion and amount of displacement also decreased, until on the sixth or seventh passing (20 to 30 seconds after onset of rotation) they were harmonious, and the subject perceived himself as stationary while the plane rotated around him rapidly.

Similar effects were also observed at slower rotation speeds to the left. They became less and less pronounced as the acceleration decreased, until at a rotation rate of 3 rpm there seemed to be no significant change in the velocity of the motion of the target to the right upon the onset of rotation. However, the subject again noticed that his own rotation appeared to diminish and disappear, while that of the model plane increased until it had reached a maximum at the third appearance.

2. Deceleration effects:

In general the deceleration effects were much stronger than those during acceleration. This was true because the deceleration times were less than 0.5 second in each case, as compared with the acceleration times noted above.

When the subject, rotating to the right at 15 rpm, was suddenly stopped, the target appeared to move very rapidly to the left. In some cases it even seemed to be momentarily displaced slightly to the left and then to be slowly displaced to the right until it disappeared. Thus the subject saw the plane moving to the left, but at the same time he had to keep turning his eyes to the right to see the target. This effect persisted until the plane disappeared but was lost by the time the plane reappeared.

In conformity with the observations during acceleration, the deceleration results were similar when slower rates of rotation were used. The immediate post-rotation effect was a sensation of turning to the left. After lower rates of rotation, the displacement of the plane was slow and to the right, and at the same time the subject initially observed apparent motion to the left. The target then appeared to lose all motion. This was followed by slow motion off to the right in the direction of the displacement.

The deceleration effects observed following rotation at 15 rpm to the left were quite pronounced but somewhat less spectacular than following comparable rotation to the right. The target light appeared to move at high speed to the right, but the displacement lagged well behind; i.e., there was a marked discrepancy between the displacement and the observed motion. Similar though less marked effects appeared at slower speeds of rotation.

DISCUSSION:

These perceptions of movement of the target light can be considered as a resultant of the interaction between the real velocity and direction of movement of the target and the rate and direction of the slow phase of nystagmus since the fast phase is disregarded. With the target moving slowly to the right, onset of rotation of the subject to the right or to the left results in an immediate nystagmus with the slow phase opposite to the direction of rotation. Dodge[7] has shown that these nystagmoid reactions are reflex in origin, as indicated by their very short reaction latencies, and that they are of such magnitude of angular deviation as to maintain a fixed image on the retina, although this deviation is not precisely accurate. Thus we have found that with the image fixed on the retina the target although in motion is perceived as motionless. With successive rotations of the subject the nystagmus tends to diminish and finally to disappear. At this time the subject has lost his own sensations of rotation. Eye movements which tend to maintain fixation of the target while it is in view differ in no way from ordinary pursuit movements, and subjectively the movement is attributed to the target.

Whatever the effects of eye-movement on motion perception, the displacement of the target is necessarily perceived, since, when the retinal image is fixed, the eye must turn to maintain the fixation. This eye-turning signals displacement.

The effects observed during the deceleration and post-deceleration period may be explained by the same reasoning. The immediate eye-movement response to deceleration is a nystagmus, with the slow phase in the same direction as the previous rotation. In this case, however, the nystagmus will not serve to maintain a fixed retinal image but rather to produce such tracking of the image as to make the target appear to move in a direction to this will occur only when the previous rotation was in the same direction as the movement of the target and the resulting rate of nystagmus was just sufficient to maintain a fixed image. When the tracking movement interacts with the real move-

[7] R. Dodge, Adequacy of reflex compensatory eye-movements including the effects of neural rivalry and competition. J. exper. Psychol., 1923, 6, 169-181.

ment of the target, the resultant rate will merely be added to or subtracted from the real movement, depending on whether the tracking is opposed to, or complementary with it.

The actual displacement of the target is, however, always to the right; the saccadic eye movements in nystagmus will carry the fixation back to the target plane, and each one finds it displaced farther to the right. Thus it may result that, because of tracking of the retinal image, the object is seen to move in one direction, yet is seen to be progressively displaced in the opposite direction.

Similarly, when nystagmus causes tracking of the image in the same direction as real movement and displacement, the rate of movement is speeded up by the tracking of the image, and the eye must constantly, by saccadic movements, go back to refixate the target. The resulting perception is that of the target's undergoing a rate of movement too great to be compatible with the resulting displacement.

The causal factors resulting in these phenomena of apparent movement are essentially the same as those involved in stroboscopy by impressed eye movements reported by Metfessel[8]. The explanation is similar to that offered by Warren[9] for the stroboscopic effects.

Early students[10] of perceived movement realized that the perception of motion is a function of the stimulus affecting successive retinal elements. However, they were also well aware of the fact that movement could be seen as movement independent of displacement. They were also aware that such perceptions were complicated by the subject's perceptions of his own motions, by ocular nystagmus, and by afterimages of motion. These experiments are in accord with these earlier studies and clearly show that motion and displacement can be perceived independently and in opposition to each other. It is clear that real and apparent motion of an object are readily confused at small velocities, when visual references are lacking, and particularly when the perception is complicated by nystagmus and feelings of rotation of the observer himself.

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[8] M. Metfessel. Stroboscopy by means of impressed eye movements or mirror vibration. Science, 1933, 78, 416-417.

[9] N. D. Warren. An explanation of Metfessel's stroboscopic effect observed in mirror vibration, J. Gen. Psychol., 1934, 10, 463-465.

[10] E. G. Boring. op. cit.

These results have important implications for flying. This is particularly true during night operations and instrument flights where normal visual references are meager or lacking. Confusions under such circumstances have been observed at one time or another by most pilots and have been classified under the general heading of "vertigo". Numerous factors contribute to "vertigo" and the illusory types of movement here described re-emphasize and clarify the dangers of maneuvers which contribute to confusions in relative movement during night flying.